

The above is followed by a discussion of the problems of heat flow in connection with the copper, iron and insulating parts, indicating, in a general way, where the principal temperature drops occur. This is followed by a general discussion of copper, iron and air friction losses and a rough indication is given as to the enormous volumes of cooling air required by such machinery.

Temperature determination is next taken up, with a short discussion of the methods approximating the highest temperature, by means of embedded detectors.

The paper is intended to be educational in the sense that it points out what the actual turbo-generator problems are, in so far as they concern turbo ventilation. It does not attempt to go into the quantitative solution of such problems.

Some Practical Experience with Embedded Temperature Detectors

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ENGINEERS are interested in the maximum armature coil temperatures and in the average temperature of the embedded portion of the coil. Only the former are discussed at length in the paper, and test data are submitted to bear out the statements; in general the test data include temperature measurements on the bare copper.

There may be very material errors due to improper installation of the detectors; and even if properly installed between coil sides, the detector does not read the maximum copper temperature. The principal reasons for the latter are that there is a flow of heat from the adjacent sides of the copper in the upper and lower coils to the slot sides, and that there is a difference in temperature between the upper and lower coils. The heat flow to the slot sides is augmented by the fact that the longitudinal thermal conductivity of built-up insulation is from three to ten times the transverse conductivity. Even with an isotropic medium the flow of heat to the slot sides lowers the detector reading. The relative side flow is increased with increase in distance between copper conductors in upper and lower coil sides.

The difference in temperature between the copper in the two coils is due principally to difference in eddy current loss, arising from the cyclic change of leakage flux. The eddy loss in the top coil is lowered if the throw of the coils in the particular slot in which the detector is placed is such as to increase the phase angle between the currents in the two coils, as is proved by test data.

The principal sources of errors pointed out in the paper, arising from improper installation of detectors between coil sides, are due to the wrapping of the upper and lower coils individually, thereby permitting cool air at the vents to lower the detector temperature, and

the use of wide detectors. Test data on a 12,000-kv-a alternator and on a model of an armature with thermocouples on the bare copper, as well as between coils, with the one and two slot cell arrangements are submitted; and in addition, in the case of the model, data with wide and narrow resistance exploring coils are given. In order to show that the air currents which lower the detector readings did not lower the internal temperatures, data are also incorporated, in the case of the model, with packing between the coils. The data confirm the statements in regard to errors. It further seems from the data that there is a greater difference between the maximum and minimum readings with detectors between coils exposed to the cooling air than with detectors similarly placed but protected from the air, and the difference is smallest with detectors on the bare copper.

Detectors at the bottom of a slot in the 12,000-kv-a. alternator, and at the bottom of a slot and under wedge in a 3750-kv-a. turbo generator showed (in conjunction with readings on the bare copper) that detectors so placed cannot read the copper temperature, nor in any way give an indication of the thermal drop through the insulation. The detector reads the temperature of that part of the iron or wedge with which it is in contact.

Tests show that the copper at the top of the upper coil is not necessarily at the highest temperature, because the wedge is usually cooler than the iron. If the maximum copper temperature is sought, detectors should be placed at various depths in the upper coil.

The paper concludes with a summary, conclusions and remarks. Other points than those previously cited in this abstract are that: all heat from the copper must flow transversely through the insulation; the thermal drop through the insulation in large, long-core, high-voltage, 60-cycle machines is of the order of 50 deg. cent.; the thermal drop in the insulation, in long-core machines can not be appreciably lowered by improvement in ventilation; thermometers placed on the end

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windings, in general, give no information in regard to the highest copper temperature; resistance measurements taken after completion of the heat run, convey no information in regard to maximum temperature, and but little information in regard to the average temperature in the slots; the machine usually cools too much after shut-down and before taking readings to obtain accurate data on the average temperature of the winding.

The method of measuring temperatures by detectors in the upper coil is not usually commercial; therefore it would be best to continue with detectors between coils, protecting the detectors from external air currents. The detector reading is then a means of judging the maximum copper temperature, and as such may be used for comparison of readings between machines.

Calculation of Magnetic Force on Disconnecting Switches

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THE practical problem of calculating the magnetic force tending to open a disconnecting switch is a useful one to solve. The result is expressed in concise form in formulas (20) and (21) and curves are also given in Figs. 3 and 4 from which the force may be found without using the formulas.

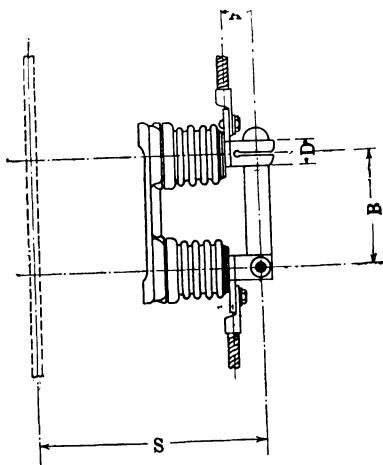


FIG. 1—FRONT-CONNECTED DISCONNECTING SWITCH

The solution of this problem is useful not only to the designers of switches who must design the parts so as to withstand the maximum force to be expected, but also to the designers of circuits containing disconnecting switches, for it is often desirable to choose a form of circuit which will produce the least possible force on the switch. The formulas and methods of calculation may also be used for calculating the forces on different parts of circuit breakers and other types of apparatus.

The mechanical force tending to move the blade of a switch which is carrying current, is proportional to the strength of the magnetic field in which the blade lies. The fundamental formula which should be used in making calculations of this kind states that the strength

of the magnetic field at a point P , due to a small length of conductor dx at a point Q is equal to

$$\frac{I dx \cos \theta}{P Q^2}$$

where I is the current in absamperes and θ is the angle between PQ and the perpendicular from P to the line through dx . This may be found in standard text books such as J. J. Thomson's "Mathematical theory of Electricity and Magnetism," Fourth Edition page 356.

The field in which the blade lies is calculated in four parts, each depending on part of the typical circuit shown in Fig. 5.

TYPICAL CIRCUIT

This typical circuit consists of a flat blade of length B , two round arms of length A , and connections parallel to the blade. The diameter and shape of the parallel connections do not appreciably affect the result. A typical circuit of this type most nearly corresponds to disconnecting switches as used in practise, and it is believed that it gives a calculated force which is correct within a small percentage.

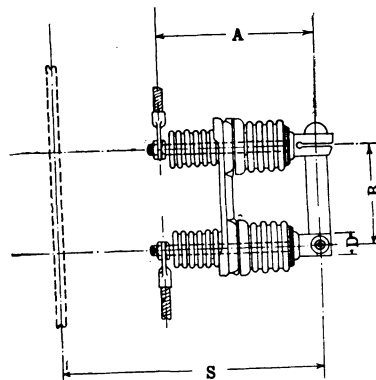


FIG. 2—REAR-CONNECTED DISCONNECTING SWITCH

The formulas are first obtained in algebraic form, but they are greatly simplified for practical use by engineers by expressing them as convergent series. Separate series must, however, be given for the two cases of A greater than B , and A less than B . For this purpose, the following series are required:

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